ON THE MECHANICAL ORIGIN OF TWO-WAVELENGTH TECTONICS ON GANYMEDE. Laurent G.J. Montési[1] and Geoffrey C. Collins[2], [1]Woods Hole Oceanographic Institution, Dept. Geology and Geophysics, WHOI MS24, Woods Hole MA 02536, montesi@whoi.edu, [2]Wheaton College, Astronomy and Physics Dept., 26 E. Main Street, Norton, MA 02766, gcollins@wheatonma.edu

Summary: Deformation of bright terrain on Ganymede occurs at two wavelengths: Fault spacing of order 1-2 km, and topographic undulations of order 10 km. Necking has been invoked to explain the longer wavelength but may be questionable if the strength of brittle ice increases significantly with depth. The short wavelength can be explained through localization instability. Numerical models show that long-distance fault interaction can produce regularly-spaced zones of enhanced deformation that may an alternative origin for the long wavelength deformation on Ganymede, especially in low strain areas.

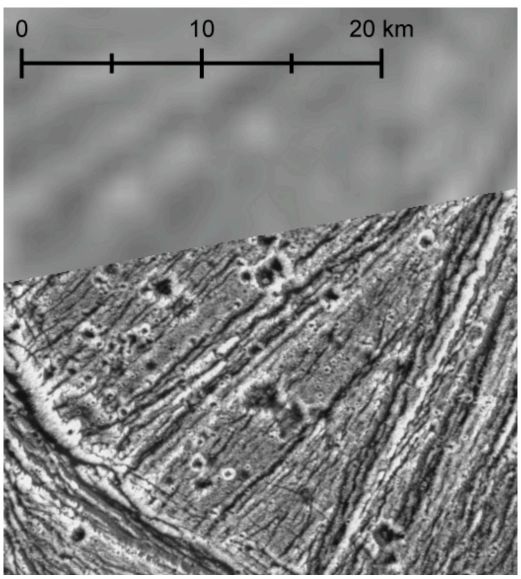

Figure 1: Fractures in the NE corner of the G1 Uruk Sulcus area. Fractures are concentrated into narrow bands separated by undeformed regions. Two wavelengths of deformation are apparent, one in the spacing of faults within each band, the other in the spacing of bands, also visible in the background Voyager image

Two-wavelength deformation on Ganymede: Since Voyager revealed the bright terrain of Ganymede and the tectonic structures within it, there has been debate as to what controls the observed tectonic wavelengths. From Galileo and Voyager imagery, it appears that at least two length scales are present in the highly extended terrain. A short length scale of order 2 km is generated by the spacing of faults. A longer length scale of order 10 km is visible in the topography of the terrain [1; Figure 1].

Necking or localization instabilities?: The longer length scale of deformation, being somewhat diffuse in its expression, is reminiscent of the theory of necking developed originally for the formation of outcrop scale folds and boudins and later generalized to large-scale tectonics [2, 3]. Dombard and McKinnon [3] showed in particular that the necking instability could be at the origin of the tectonic style of the grooved terrain, provided that updated rheologies and a low surface temperature appropriate for the conditions 3-4 By ago be used. In the process, they determined a rather high heat flux (~80 mW m^{-2}) at the time of groove formation. Such high heat flux is corroborated by the flexure analyses of Nimmo et al. [4] and requires a component of tidal heating at the time of groove formation.

These analyses have largely ignored the short wavelength of deformation. By analogy to the Basin-and-Range, the shorter wavelength of deformation may indicate a layered structure in which strength is supported at two different levels separated by a decoupling zone [5]. However, this would imply a significantly different thermal and/or compositional structure of the ice crust than used in previous instability models.

The localization instability [6] predicts that two wavelengths related to faulting develop simultaneously in a single layer. If the longer wavelength is tied to necking, the shorter faulting wavelength can match the observations thanks to an adjustable parameter that quantifies the rate of weakening and the efficiency of localization. Unfortunately, this parameter is unconstrained for most natural materials, including low-temperature ice.

Trouble with necking: One caveat of the necking instability analysis is that it is tractable analytically only if the viscosity of the layers is constant or changes exponentially with depth. This restriction is lifted with the use of a simple numerical integration [6]. This is particularly important for brittle layers, as their strength is expected to increase linearly with depth. However, the growth rate of the instability is significantly reduced when the brittle strength is let to increase linearly with depth. In fact, this effect is sufficient to make the necking instability irrelevant for the lithosphere (Figure 2).

Although this analysis implies that the necking instability is not relevant for planetary tectonics, it should be pointed out that the analysis assumes a homogeneous lithosphere and infinitesimal perturbations of the various layers that it constitutes. In reality, heterogeneities may induce necking. In addition, finite strain effects may produce structures similar to necking. However, this is speculative. We should therefore be cautious in matching topographic wavelengths on Ganymede to the wavelengths expected from necking with a constant strength brittle layer.

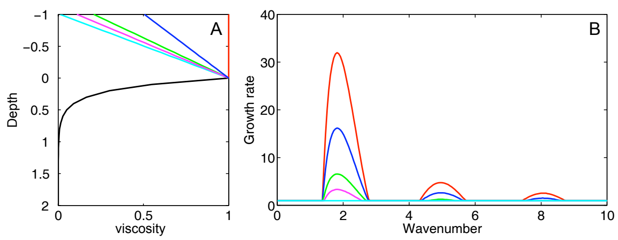

Figure 2 A) Strength profile and B) corresponding growth spectrum for a simplified lithosphere models consisting of a pseudo-plastic layer of unit thickness and strength increasing linearly with depth overlying a ductile substrate with exponentially-decaying viscosity. Incorporation of depth dependent brittle strength decreases the growth rate of necking

Localization can help: Although necking is reduced when realistic strength profiles are considered, this does not imply that two wavelengths of deformation cannot develop simultaneously in an extending lithosphere. Indeed the localization instability can on its own produce two wavelengths of deformation: a short wavelength expressed as fault spacing [6]; a longer wavelength due to long-distance fault interaction. The latter may be related to necking.

The semi-analytical instability analysis allows predictions of the two faulting-related wavelengths. However, fully numerical models are needed to predict the morphology produced by this interaction. For that purpose, we use a Finite Element code (LAYER [7]). Structures similar to the grooved terrain are obtained of deformation of an ice crust with surface temperature of 120K, heat flow of 25 mW m^{-2}, and a weakening parameter of 0.25 quite stronger than inferred for terrestrial structures. An alternative model uses a surface temperature of 100K, heat flow of 50 mW m^{-2}, and a weakening parameter of 0.15.

We hope to identify further conditions that lead to similar structures, especially for lower surface temperature. Higher heat flux is obviously required if the surface is colder. Preliminary results seem to indicate that the implied weakening factor also decreases when the surface is colder, which makes the model more Earth-like. There is however no independent information on this parameter for ice.

References:

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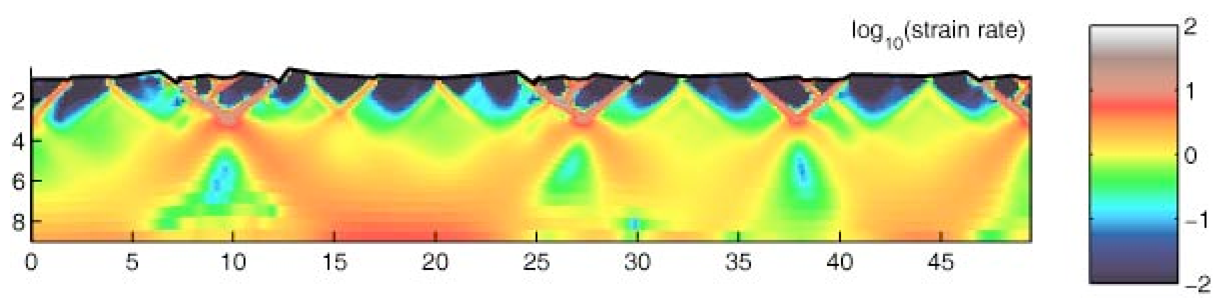

Figure 3: Numerical prediction of fault pattern in a 9-km thick layer of ice stretched at the rate 10^{-15} s^{-1}. The Finite-Element model (code LAYER) shows faults separated by ~ 2km and a long-baseline fault interaction controlling the development of grabens separated by ~12 km. The surface temperature is 120 K and the heat flow is 25 mW m^{-2}. In each element, the selected rheology is the weakest of a brittle failure envelope and both the dislocation creep and GBS flow laws of Goldsby and Kohlstedt (2001). Weakening in the brittle regime occurs at a rate of 30% per decade in strain rate. The colors show the strain rate scaled by the background rate. Although the flow solution is instantaneous and valid only when there is no deformation, the model has been stretched by 10% in one time step in order to visualize the deformation field.